it constituted in my own experiments the chief and most striking phenomenon: and it was to the colours which appeared during the bright phase that my attention was exclusively directed, the tints of the relatively insignificant "luminous trails" being too faint to be distinguishable.

It is clear that the momentary excessive brightness of the positive image is no less essential than the dark interval (or negative after-image) for the generation of the phenomenon of recurrent vision which forms the subject of the present paper.

III. "Niagara Falls as a Chronometer of Geological Time." By J. W. Spencer, Ph.D. Communicated by Professor T. G. Bonney, F.R.S. Received March 16, 1894.

(Abstract.)

1. *Conjectures as to the Age of Niagara Falls.*—Prior to the writing of the present paper, most of the conjectures as to the age of the Falls have been based simply upon the supposed uniform rate of recession. Thus, in 1790, Andrew Ellicott assigned 55,000 years as the age of the Falls. In 1841, Sir Charles Lyell allowed 35,000 years; in 1886, Professor R. S. Woodward, after three surveys had been made, calculated the age as 12,000 years; and later, Mr. G. K. Gilbert, supposing the recession to progress at the maximum axial retreat alone, reduced the age of the Falls 6,000 years. This latter was not intended as an estimate, as he fully recognised that such a time must have been greatly lengthened by many changing conditions. The rate adopted by the first two writers was only conjectural, as no surveys had then been made. Three surveys had been completed before the writings of the latter two writers, and I have had the benefit of a fourth. Woodward's calculation was upon the mean mathematical enlargement of the Horseshoe gulf at the end of the chasm, which rate was less than the geological rate of retreat. The author's method differs from the others in that it takes into consideration the rate of recession throughout the changing episodes of the river, which have been entirely discovered by Gilbert or himself. His computations make the age surprisingly near to the conjecture of Lyell.

2. *Modern Topography.*—This section of the paper gives such details as bear upon the subject, some of which do not appear elsewhere.

3. *Geology of the District.*—Besides what may be found in other works, there are several measured sections and descriptions showing the amount of work the river had to do. Several figures illustrate the varying conditions.

4. *Ancient Topography.*—The Niagara is a modern river. It crosses a broad ancient valley nearly 100 ft. deep, in the vicinity of the Falls. This depression has largely escaped the attention of even geologists, and entirely in its bearing upon the history of the Falls. The peculiar extension of the chasm at the Whirlpool, and the buried valley of St. David's, have been considered by many as part of a preglacial Niagara river. This is now found to be a branch of a buried valley outside the Niagara *cañon*, and hundreds of feet shallower, with ancient sloping V-shaped walls, whilst those of the gorge are vertical. It is only an incident that the modern river touched this drift-filled valley, but it has given rise to the elongation of the chasm at the Whirlpool. The drainage of the tableland in ancient times was across the direction of the Niagara river, and was strongly marked by bold limestone ridges, which have only been penetrated by the Falls in modern times. Even the Erie basin emptied by a route several miles west of the Niagara.

5. *Basement of the River.*—In order to explain the work done by the river, this feature is described, part of the banks of the original course, before sinking into the chasm, being on hard rocks, and part on local deposits of drift. Even the deserted river banks carved out of such accumulations are still well preserved.

6. *Discharge of the Niagara River.*—This is only important in order to learn what is the discharge of the Erie basin alone; for during a considerable portion of the life of the Niagara only the Erie waters fell over the falls. The drainage of the Erie basin is 3/11 of that of the four great upper lakes.

7. *Modern Recession of the Falls.*—From four surveys, extending over a period of forty-eight years, the mean modern rate of recession of the Falls is found to be 4·175 ft. a year. Its rate is variable with secular episodes of rapid medial recession, followed by its cessation along the axis, but with increased lateral retreat. This cycle appears to take about fifty years. But the detailed figures are given with a map. This rate is, however, excessive, on account of the geological conditions favouring the rapid modern recession, but the rate taken for the mean recession under the conditions of the modern descent of the river with the present discharge is 3·75 ft. a year.

8. *Sketch of the Lake History and the Nativity of Niagara River.*—At one time a great proportion of the lake region was covered by a single sheet, or the Warren Water. Upon its dismemberment—in part, at least, by the rise of the land—one large lake was formed occupying the basins of Huron, Michigan, and Superior; and another a portion of the Erie extending into the Ontario basin. The waters in these two basins were subsequently lowered, so that they fell to their rocky eastern rims, and the three upper lakes discharged by way of Lake Nipissing and the Ottawa river, and the Niagara had its birth,

draining only the Erie basin. Then the Niagara river descended 200 ft. In course of time the waters subsided 220 ft. more, but eventually they were raised again 80 ft. at the mouth of the Niagara, thus reducing the descent of the river, from the head of the rapids above the falls to the foot of the last rapids in its course to the lake, to 320 ft. During the lowest stage, Ontario lake receded twelve miles from the end of Niagara gorge, where the falls had been located at their nativity.

9. *Laws of Erosion.*—Theoretically the erosion varies as the height of the falls and the volume of the water, but some of the work is converted into heat. The recession is largely due to the work being expended in the undermining of the hard capping rocks, by the removal of the underlying shales. The rate of the modern recession has been determined under the changing conditions of erosion, so that the theoretical variations of other portions of the river's work includes their modification.

10 and 11. *Episodes of the River and the amount of Recession in each. Duration of each Episode.*—First episode: Water falling 200 ft., in volume 3/11 of modern discharge; gorge, 11,000 ft. long; duration, 17,200 years. Second episode: river descending 420 ft., in three cascades; first stage, only the discharge of the Erie waters; length of chasm, 3,000 ft.; duration, 6,000 years; second stage, drainage of all the upper lake; length of chasm, 7,000 ft.; duration, 4,000 years. Third episode: same volume and descent as in last, but the three falls united into one fall; length of chasm, 4,000 feet; duration, 800 years. Fourth episode: volume of water as at present, the level of lower lake as to-day; first stage, a local rapid making the descent of 365 ft.; work particularly hard; length of gorge, 5,500 ft.; duration about 1,500 years; the second stage as at present; work easy; length of *cañon*, 6,000 feet; descent of water, 320 ft.; rate of recession here taken as the full measured amount of 4·175 ft. a year; duration, 1,500 years. Thus the age of the falls is computed to be 31,000 years, with another 1,000 years as the age of the river before the nativity of the Falls. The turning of the Huron waters into the Niagara was about 8,000 years ago. A difficult question was the amount of work done in each episode. This was in part determined by the position of the remaining terraces corresponding to different stages of the river, and by the changing effects of erosion.

12. *Relations between the Terrestrial or Epeirogenic Movements and the Falls.*—The deserted beaches in the lake region have been deformed by unequal terrestrial elevation, and this movement has caused the changing conditions of the river in a large part, such as the turning of the Huron waters from the Ottawa valley to the Erie basin. This deformation affecting the Niagara district, since the commencement of the river epoch, amounts to 2·5 ft. per mile; east of Lake Huron,

4 ft. per mile; and at the outlet of Lake Ontario, 5 ft. per mile; all in a north-eastward direction. Taking the amount of movement in each district as representing also the proportional measure of time, then calculations can be made upon several of the beaches, and in terms of the age of Niagara their antiquity can be inferred. The importance of the computations in this paper is that they support the correctness of the calculated age of the Falls. In the application of these results it appears that the rate of terrestrial uplift in the Niagara district is about 1·25 ft. a century; 2 ft. east of Lake Huron, and 2·5 ft. at the outlet of Lake Ontario. Here was found the first long looked-for indication of the rate of uplift.

13. *The Relation of Niagara Falls to Geological Time.*—From the study of the deserted beaches, it appears that the commencement of the lake epoch was as long before the birth of Niagara Falls as the Falls are old, so that the beginning of the lake age was probably 64,000 years ago, or perhaps even 80,000 years. Against this conjecture we have as yet no proof. On the other hand, some suppose the lakes to have been held in by glacial dams, continuing for long episodes at the same level, and by the withdrawal of the glaciers the waters were lowered in addition to the terrestrial deformation. With this assumption, the retreating ice continued until the end of the Iroquois episode, or from our computations until 14,000 years ago. But here we need much more investigation. The present paper is merely a contribution in a field of work in America, in which only a few workers have so far contributed the detailed labours upon which this study is built.

14. *The End of the Falls.*—From the rate of terrestrial elevation and the rate of recession of the Falls, it appears that if the movements continue as they have been progressing, then before the Falls shall have retreated to Lake Erie, the Niagara outlet will have been deserted, and the waters of the upper lakes will discharge by way of Chicago into the Mississippi drainage, a change analogous to the turning of the Huron waters into the Erie valley from the Ottawa outlet. This change might be expected 7,000—8,000 years hence.

IV. "The Influence of Intra-Venous Injection of Sugar on the Gases of the Blood." By VAUGHAN HARLEY, M.D., Teacher of Chemical Pathology, University College, London, Grocer Research Scholar. Communicated by GEORGE HARLEY, M.D., F.R.S. Received May 9, 1894.

In a paper on "The Effects and Chemical Changes of Sugar injected into a Vein"* I showed that when grape sugar is injected

* 'Roy. Soc. Proc.,' 1893.